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Christensen, Justin; Dennison, JR; and Dekaney, Justin, "Diverse Light Emissions from Epoxy Due to Energetic Electron Bombardment" (2013). American Physical Society Four Corner Section Meeting, University of Denver, Denver, CO. *Posters.* Paper 20.
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Diverse Light Emissions from Epoxy Due to Energetic Electron Bombardment

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October 18th & 19th 2013
University of Denver, Denver, CO
2013 APS 4CS Meeting

Abstract

Dielectric materials subjected to energetic electron fluxes can emit light in several forms. We have observed three distinct types of emissions: (i) short-duration (<1 ms), high-intensity electrostatic discharge (ESD) or "arc" events; (ii) intermediate-duration, high-intensity events which begin with a bright arc followed by an exponential decay of intensity (~10 to 100 sec decay constant), termed "flares"; and (iii) long-duration, low-intensity emission, or cathodoluminescence, that continues as long as the electron flux is on. These events were studied for bulk samples of bisphenol/amine epoxy, using an electron gun with varying current densities (0.3 to 5 nA-cm^{-2}) and energies (12 to 40 keV) in a high vacuum chamber. Light emitted from the sample was measured with high-sensitivity visible and near-infrared video cameras. We present results of the spatial and temporal extent for each type of event. We also discuss how absolute spectral radiance and rates for each type of event are dependent on incident electron current density, energy, and power density and on material type, temperature, and thickness. Applications of this research to spacecraft charging and light emissions are discussed.

Introduction

Spacecraft can emit light, due to energetic electron bombardment from the space plasma environment.[1] With space-based observatories, this can be bad if detectors collect light that did not originate at the objects being observed.

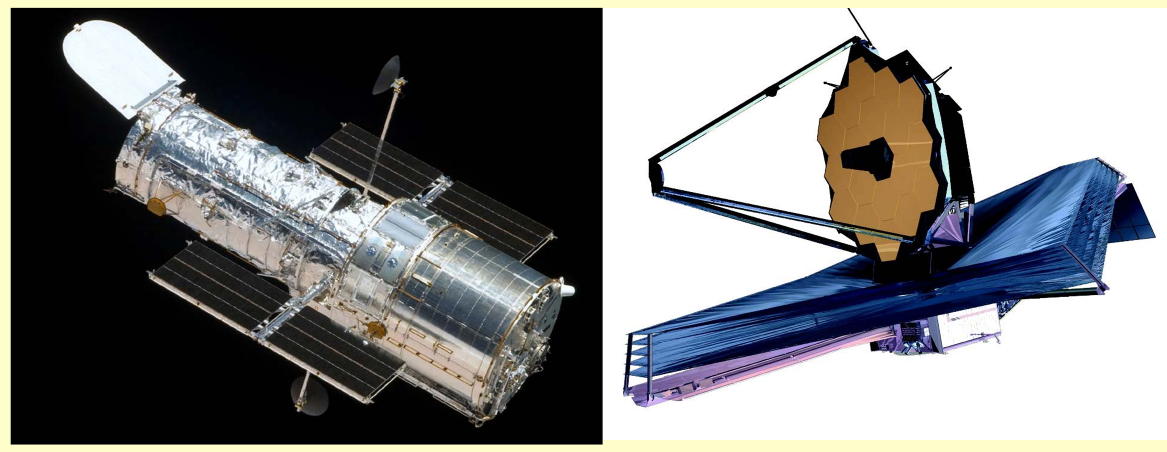
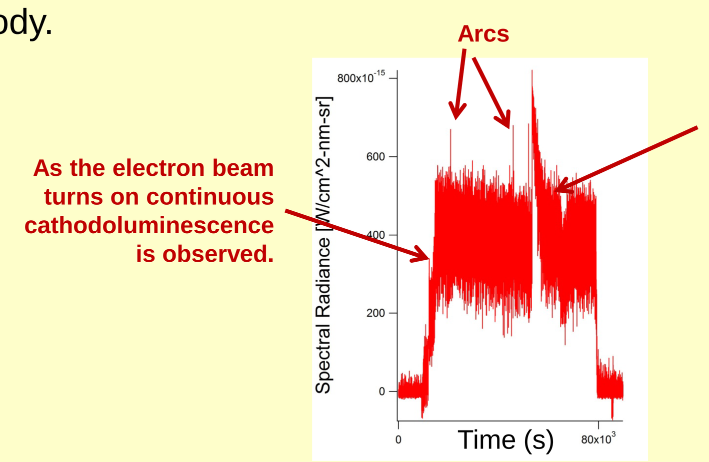


Fig.1. While it is possible to build shielded structures like the Hubble Space Telescope (left), some advanced space-based observatories have open architectures, because of their large size and the extreme costs of getting more weight in orbit.

There are three distinct forms of photon emission which have been observed in this type of environment:

- **Cathodoluminescence** is a continuous emission of photons that can be observed any time energetic electrons are incident on a material.
- **Flares** are intermediate duration(10 to 100 sec exponential decay constant) photon emissions which begin suddenly and then have an exponential decay.
- **Arcs** are very short duration(<1ms) flashes caused by rapid discharge of a charge body.



Cathodoluminescence Basics

- Cathodoluminescence occurs when an incident energetic electron excites a valence band electron in a material into the conduction band.
- These excited electrons can then decay into long-lived, localized (trapped) states, where they can either be re-excited by incident electrons or fall into deeper trapped states.
- As an electron moves from an excited state to a lower energy state it emits a photon with energy equal to the change of energy.
- In materials that contain trapped states of varying depths the emitted photons have varying wavelengths which can be measured with a spectrometer.

Results

Three types of photon emission were studied for bisphenol/amine epoxy. Studies were conducted for 36 epoxy dots of ~1 mm diameter. Some epoxy dots were more active than others. A key objective of the study was to understand the variability of the magnitudes of these light emissions and their rates.

Cathodoluminescence

The intensity of cathodoluminescence for a given incident electron energy and current was approximately constant, as long the beam was on. For the low current densities used in these tests, the relation between current density and spectral radiance is linear. To compare spectral radiance vs energy, we scaled intensity to a constant current density of 10 nA/cm^2, approximately equal to the current in typical space weather storm conditions. Scaled spectral radiance was plotted vs. electron energies showed a linear relation, that is intensity scaled with incident power density (current density times beam energy).

To gauge the severity of epoxy cathodoluminescence during a typical storm, the scaled spectral radiance is compared to the faint background glow or zodiacal background. [2] Our results show that a patch of epoxy in the direct optical path of a telescope is 3X to 10X brighter than this zodiacal background.

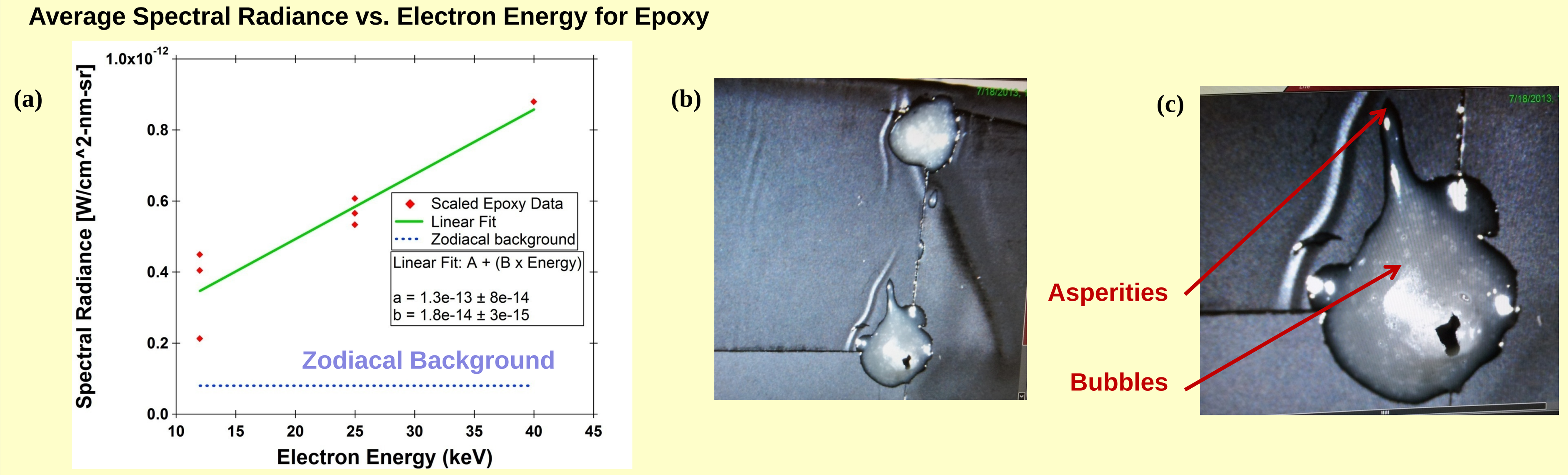


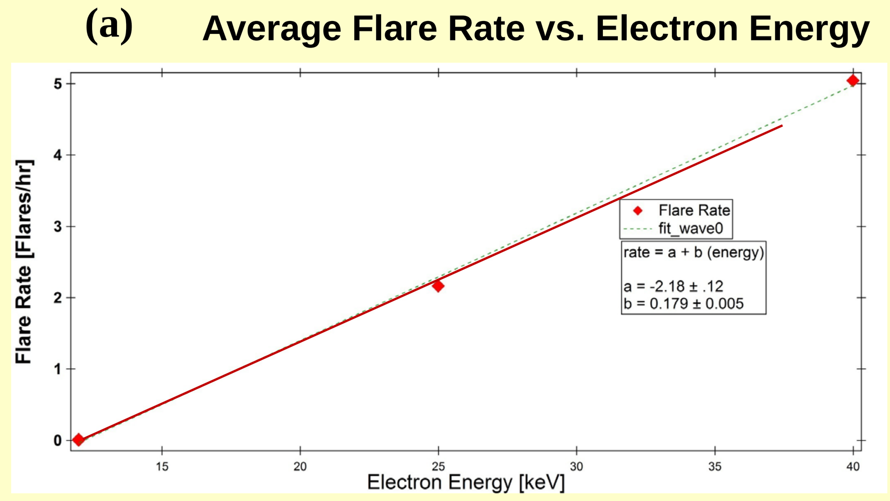
Fig.2. (a) Measured spectral radiance for epoxy dots vs incident electron energy at 10 nA/cm^2. Glow is brighter than zodiacal background. **(b)** Epoxy dots under a microscope. (**c)** Higher magnification view, showing asperities and bubbles in this enlarged photo.

Flares

Flares were manually counted for each epoxy dot spectral radiance vs. time graph after smoothing.

Flare rates are shown in Table 1
5 of 36 epoxy dots had 4 to 6 flares during 25 keV run.
12 of 36 epoxy dots had 0 flares during 25 keV run.

Possible reasons for the variation in activity are differences in dot shape, presence of contaminants, air bubbles, and variations in the electron beam profile.



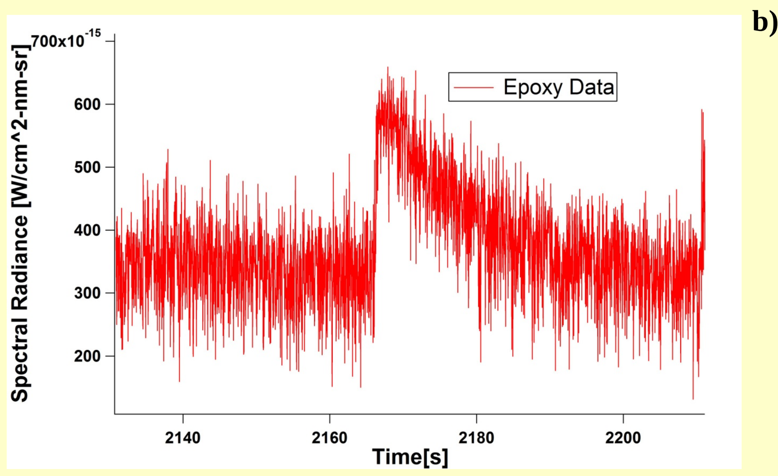


Fig.3. (a) Linear relation between average flare rate and electron energy. **(b)** Spectral radiance vs. time for typical flare. A flare begins with a sudden jump in intensity followed by an exponential decay. This flare lasts ~ 30 sec.

Table 1

Energy	Flares/hr
12 keV	0 ± 0.5
25 keV	2 ± 0.5
40 keV	5 ± 0.5

Arcs

Arcs were counted using a program which counted the number of times the spectral radiance had a value greater than 1.75 x the standard deviation. When compared to the known number of arcs for one of the epoxy samples this method gave false data. Therefore further analysis is needed to compare arc rate to electron energy, flux density, and power density.

Experimental Methods

Data were collected by Justin Dekany (USU), Chuck Bowers (NASA/GSFC), and Todd Schneider (NASA/MSFC) at MSFC.

- Sample was mounted inside a vacuum chamber, which was cooled ~120 K.
- Electron beams of known energy (12-40 keV) and flux density (<5 nA/cm^2) were used to bombard the sample.
- Current density from the sample was monitored with electrometers.
- Intensity from the sample was monitored with an image-intensified CCD video camera (~400 nm to 900 nm).
- Video files were stripped into individual jpg images.
- Images were analyzed by a MatLab program to determine average intensity per pixel for sample and background regions.
- Background signals were subtracted.
- Data were multiplied by a calibration factor to obtain the absolute spectral radiance for each sample (epoxy dot) area.

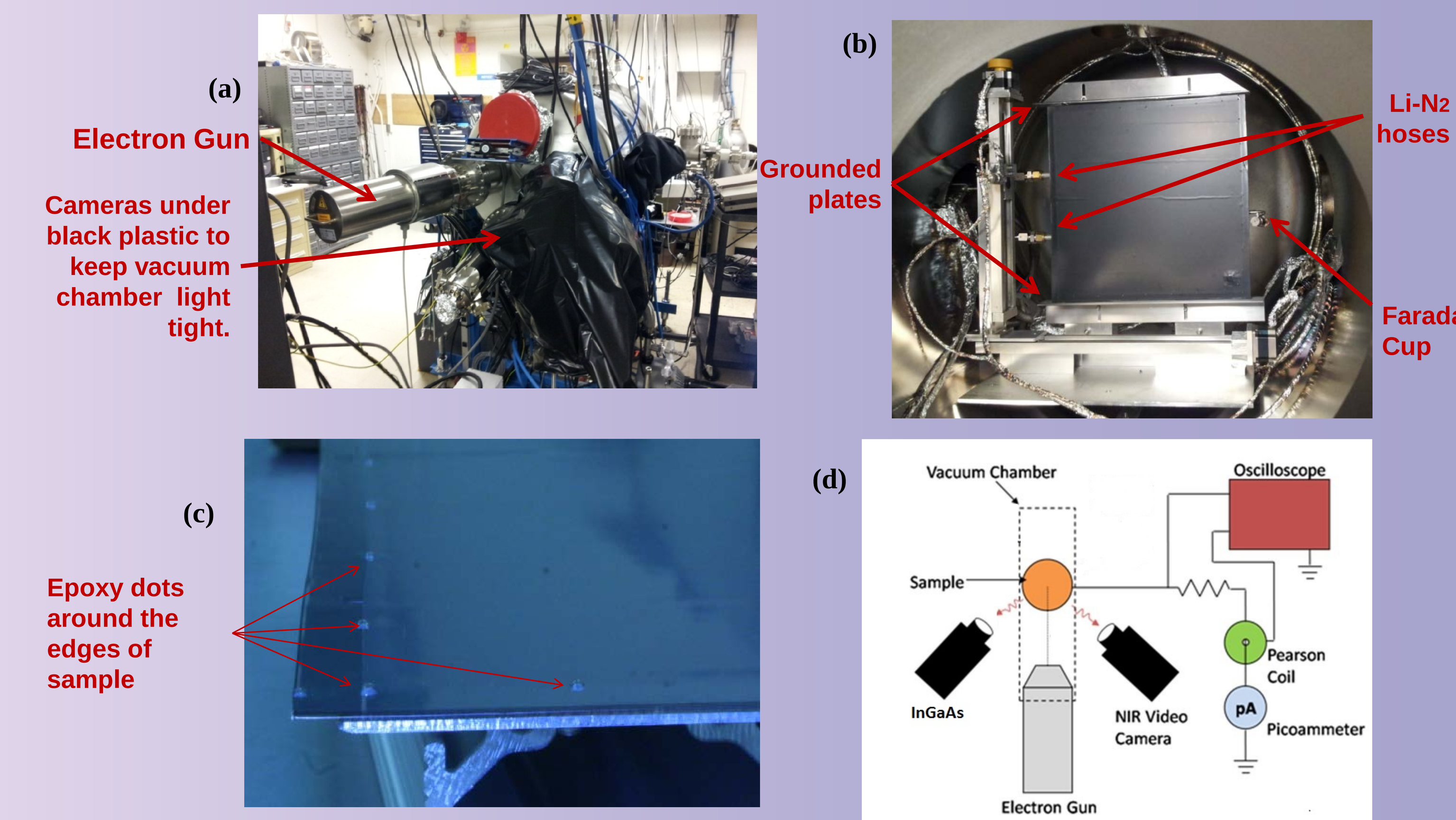


Fig.4. (a) Vacuum test chamber at Goddard Space Flight Center (GSFC) . **(b)** Photo was taken from a port just below where the CCD camera was positioned, showing the sample area. **(c)** Epoxy dots were positioned around the outside edge of this sample. **(d)** Schematic of the experiment setup

Conclusion

Three types of photon emission were observed for bisphenol/amine epoxy: arcs, flares, and cathodoluminescence. A large range of sample activities was observed possibly because of variations of size, shape, placement, contaminants, and electron beam profile. For electron fluxes and energies similar to the space environment bisphenol/amine epoxy produced photon emissions larger than the contamination from the Zodiacal background. The cathodoluminescence of this sample exhibited a linear correlation to electron energy. It was also found that the rate at which flares occurred was related linearly to the incident electron energies at a constant electron flux.

Acknowledgements

Supported through funding from NASA Goddard Space Flight Center.

References

[1] Dennison, J. R., Jensen, A. E., Wilson, G., Dekany, J., Bowers, C. W., and Meloy, R., "Diverse Electron-induced Optical Emissions from Space Observatory Materials at Low Temperatures" Proc. SPIE Cryogenic Optical Systems and Instruments Conf., Paper No. 8863-12, (San Diego, 2013).

[2] Ferguson, D. C., Krezan, J. -M., Barton, D. A., Dennison, J. R. and Gregory, S., "On the Feasibility of Detecting Spacecraft Charging and Arcing by Remote Sensing," Paper Number, AIAA-2013-2828, 5th AIAA Atmospheric and Space Environments Conference, San Diego, CA, (2013).